INVESTIGATION INTO HOT MACHINING OF En-24 STEEL BY USING RELAY CIRCUIT

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by

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dedicated to my loving parents

CERTIFICATE

This is to certify that the thesis entitled " INVESTIGATION INTO HOT MACHINING OF En-24 STEEL BY USING RELAY CIRCUIT " by Mr. S. Chattopadhyaya is record of work carried out under my supervision and has not been submitted elsewhere for a degree.

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SUBIR CHATTOPADHYAYA

CONTENTS

SYNOPSIS

This report presents experimental investigation on hot machining of En-24 steel with coromant carbide tips of S-4 grade using electric-resistance heating. A light beam sensitive relay circuit is employed to avoid sparking during engagement and dis-engagement of the cutting tool. The present investigation compares the effects of hot machining, with the use of relay and without the use of relay, on machining characteristics.

Cutting tests are carried out to study the effect of heatin current on feed force, chip-tool interface temperature, flank wear and surface finish.

Variation of flank wear, feed force, interface temperature and surface roughness with heating current are presented. Behaviour of flank wear with time and behaviour of feed force, interface temperature and surface roughness with flank wear are also presented. The following conclusions are drawn :

1. Surface finish deteriorates when machining is done without using relay but surface finish is greatly improved when the relay is used.
2. Machining without using relay causes increase in feed force and flank wear than that obtained when relay is used in machining.
3. Machining without relay causes a shift in the optimum cutti range from 100-150 amperes, obtained when machining is done with the use of relay, to 50-100 amperes to achieve minimum tool wear.

LIST OF FIGURES

CHAPTER - 1

INTRODUCTION

1.1 General :

Despite the remarkable advances that have taken place in cutting tool materials, considerable difficulties are experienced in machining high-strength temperature-resistant materials like alloys of Tungsten, Molybdenum, Titanium and Tantalum etc. Applications of these materials are largely confined to components for gas turbines, rocket propulsion units and structures of high speed aircraft and missiles. Conventional machining of these materials [1] needs to be done at very low cutting speeds resulting in low production rate and poor surface finish. Hot machining is one of the most promising processes being developed to machine these materials.

1.2 Principle of Hot Machining :

Hot machining consists in heating the workpiece, close to or slightly above the recrystalization temperature. This reduces the tendency to strain-hardening and results in the reduction of cutting forces due to decreased shear strength of the workpiece material in the vicinity of the shear zone.

Hot machining is applied mainly to turning and milling operations [2]. Application of hot machining to drilling is

not very successful due to difficulties encountered in heating the workpiece material just ahead of the drill [2].

1.3 Workpiece Heating Techniques :

The selection of a suitable heating method is a major problem in the successful application of hot machining. Heating methods vary according to the type of machining operation, workpiece material and the extent of thermal damage. The main requirements of a suitable heating technique are as follows:

a) Heating should be confined as much as possible to the shear zone.

b) A high specific heat input is required to attain a high temperature of workpiece. The temperature should not be so high as to cause thermal damage to the workpiece. The temperature to which a workpiece should be heated is a very important factor. Increasing the workpiece temperature decreases the ability of the tool to resist wearing and also decreases the shear strength of the workpiece, thereby reducing the tendency of the tool to wear. Tool life either increases or decreases with the increase in chip-tool interface temperature [3] depending on the way in which these two factors are related with temperature.

c) It should be possible to control the temperature.

d) The method employed should not be dangerous to the operator.

e) The method should be applicable to high rates of production under workshop conditions.

Several heating methods, are developed and employed in investigations [3-7] on hot machining. These methods include Furnace, Flame, Radiant, Arc, Electrical-Resistance, Inductive and Radio-frequency resistance etc. Barrow [3] studied the advantages and disadvantages of all the heating methods and concluded that the electric-resistance heating is the best technique for heating high strength temperature-resistant materials. The main advantages of electric-resistance heating technique are as follows :

a) Heat is generated at or near the shear zone.

b) Very little excess material is heated.

c) Temperature control is easy and there is quick response to temperature rise.

d) The technique is readily adaptable to production machinery.

e) Intricate workpiece shapes can be accomodated.

f) There is no danger to the machine operator since the heating current is supplied at a low voltage.

The limitations of electric-resistance heating are,

a) The tool tips must be made of electrically conductive material, thus eliminating the use of ceramics.

b) Sparking, which occurs when engaging or disengaging the tool whilst an electric current is flowing, damage the clearance face of the tool.

Sparking is a real problem in electric-resistance heating. In the present investigation, a specially designed relay circuit is used to avoid sparking.

CHAPTER - 2

LITERATURE SURVEY

Untill the mid-1940's, heating the material as an aid to improve machinability was not considered seriously except in a few steel mills where cropping ingots and cutting billets were practiced. In 1946, a member of Battelle staff suggested that the machining of certain materials might be facilitated by heating the workpiece. Several crude machining tests were carried out and it was found that tool life improved spectacularly. The increasing utilization of high strength temperature-resistant materials in the aircraft industry as early as 1957 caused interest in the techniques of machining workpiece at elevated temperatures. Between 1940 and 1951, a few papers[6-8] were published with the conclusions of decrease in cutting forces and improvement in tool life in case of hot machining.

2.1 Chip-Tool Interface Temperature :

One of the most noticeable changes in the machining parameters is chip-tool interface temperature. Barrow [3] has concluded that interface temperature increased with the increase in heating current while machining at constant speed. At constant heating current, the rate of increase in the temperature at low speeds is much more than that at high speeds. This was attributed to increased contact resistance between tool and work

at low speeds. Thus more amount of heat will be dissipated at the chip-tool interface at low speeds. He experimentally found chip-tool interface temperature at various speeds and heating currents while machining En-23 steel by carbide tools. Barrow concluded that tool life was maximum at an optimum speed of 320 ft/min. because of sharp rise in interface temperature at high speeds which caused decrease in tool life. Krabacher and Merchant [8] related tool life, T with interface temperature, θ and thrust force, F_t for mild steel as follows.

$$F_t \, \theta \, T^x = C_1$$

where C_1 = Characteristic constant = 5,30,000

x = 1/20

Groover et al. [9] developed a mathematical model for relating tool wear with temperature as follows.

$$TW = W_0 + R(T - T_0)$$

where TW = Tool wear.

W_0 = Initial interface area.

T = Thermocouple measurement.

T_0 = Ideal thermal response in the absence of wear.

R = Ratio of wear change to temperature change.

Their model provided a reasonable agreement between actual and

estimated tool wear. Recently, Kainth and Chaturvedi [10] analysed electric-resistance at chip-tool interface and at shear plane. They proposed a theoretical model for estimating temperature in case of orthogonal hot machining. Experimental values of temperature in hot machining of En-24 steel at a heating current of 200 amperes showed a good agreement with theoretical results. Boothroyd and Eagle [11] found an increase in chip-tool interface temperature with increasing wear land for conventional machining. Chen and Ho [12] carried out hot machining tests on AISI 304 stainless steel bars with carbide tool tip, having different grades, over a range of cutting speeds and feeds. They observed that tool-work interface temperature was higher when a low thermal conductivity tool grade was employed. Increase in feed resulted in increase of interface temperature but not as significant in magnitude as that obtained by increasing the cutting speed.

2.2 Tool Life :

Many investigators investigated tool life in hot machining. Barrow [3] concluded that an optimum range of heating current exists corresponding to maximum tool life. The optimum depends on the effects of reduction in cutting forces and increase in chip-tool interface temperature on tool wear. He observed an increase of 200 percent in tool life in the current range of 75 and 175 amperes while machining En-23 steel by carbide tool

using electric-resistance heating. Pentland et al. [4] carried out hot machining tool life tests on various materials. For 600 BHN AISI 4340 steel, an improvement in tool life by twenty times at a speed of 170 fpm. was reported at workpiece temperature of 900 °F. While machining 400 BHN AM 350 at workpiece temperature of 900 °F, a five-fold increase in tool life was reported. Armstrong et al. [6] investigated flame heating method on type 304 stainless steel and found an increase in tool life by 3 to 7 times at a workpiece temperature of 400 °F. Barrow [13] reported in his work on R.S. 141 steel that the proper selection of speed and feed is critical in achieving maximum tool life. Depth of cut had practically no effect on tool life at constant heating current. He reported that a tool material with a high crater wear resistance should be used due to the fact that in hot machining, rate of crater wear increases although the rate of flank wear decreases. Ellis and Barrow [14] conducted contact resistance heating tests by bar or roller electrodes on En-24 steel using K7H carbide tools. They reported that tool life is strongly dependent on the abrasiveness of the work material and abrasion resistance of the tool at lower cutting temperatures while it is more temperature dependent at higher cutting temperatures. Lo and Chen [15] predicted tool life theoretically with speed, feed, depth of cut and heating current. Basu, Pramanik and Pal [16] carried out hot machining investigation on Ni - hard Martensitic White cast iron and found that

machinability improved and tool life increased at elevated workpiece temperature.

2.3 Tool Forces and Surface finish :

Machining materials at elevated temperatures showed a reduction or increase in cutting forces. The nature of this change depends on heat treatment, composition and mode of manufacture of materials. Barrow [3] observed that cutting force reduced considerably with the increase in heating current. Thus tool life increased due to reduction in shear strength of the material. He noticed remarkable improvement in surface finish, particularly at low speeds while hot machining En-23 steel by carbide tools. This improvement was mainly due to the disappearance of built-up-edge. Marginal improvement occured in surface finish while hot machining at high cutting speeds. Pentland et al. [4] noticed excellent surface finish at high temperatures while hot machining 600 BHN AISI 4340 by carbide tools although some oxidation, to the extent of discolouration was encountered at elevated temperatures. Armstrong et al. [6] conducted tests on vitallium alloy, a useful alloy at high temperature, by flame heating. Cold machining produced glazed and uneven surface while machining at 2000 ^{o}F resulted in smooth and even surface. Tour and Fletcher [7] carried out hot machining induction heating on S-816 alloy steel and V-grade Ni steel. In all the tests, they noticed that tool forces were considerably

reduced and hot turned surfaces yielded surface finish superior to cold turned surface under same conditions. Krabacher and Merchant [8] observed decrease in tool forces with increase in workpiece temperature while conducting hot machining on AISI 3145 steel by oxy-propane flame heating technique. They suggested that the factors responsible for lowered tool forces are lowered shear strength and lowered chip friction. Barrow [17] observed decrease in tool forces with the increase in heating current while machining En-24 steel by electric-resistance heating. He concluded that tool forces decrease slightly more at low speeds and considerably more at small depths of cut for a given heat dissipation. Friedman [18] observed improvement in surface finish while hot machining by induction heating method on grade V Ni steel than that machined cold. Barrow [19] noticed considerable improvement in surface finish with increasing current on R.S.141 steel. Hot machined En-26 steel surface was also superior.

2.4 Objective of present work :

Many researchers in the past have investigated the utility of hot machining of high strength temperature-resistant materials as an aid to improve machinability and they have found reduction in tool forces, increase in tool life and improved surface finish. In electric-resistance hot machining, heat is applied at the chip-tool interface by supplying alternating

current of large magnitude through chip-tool interface. Sparking occurs when engagement and disengagement of the tool takes place. Barrow [3] has reported that sparking damage the clearance face of the cutting tool but no investigation has been undertaken so far to observe the effects of sparking on machinability.

In all previous investigations, hot machining was conducted in the absence of sparking by passing current after the tool was engaged and by stopping current supply before the tool was withdrawn from the job. The present investigation is conducted by using a light beam sensitive relay circuit to avoid sparking. To study hot machining by electric current in both the conditions of using relay and without using relay, experiments are performed on En-24 steel using sintered carbide S-4 grade cutting tool.

CHAPTER - 3

LIGHT SENSITIVE RELAY CIRCUIT

3.1 Introduction :

During a make or break of an electrical circuit, there will be a sudden change in the value of the current. The current is capable of storing energy electro-magnetically in inductances. Therefore, while an interruption of the current is attempted or the current is forced to be zero from some initial value, the electro - magnetic energy is released in the form of a spark across the pair of contacting surfaces which are made to move apart. While closing the circuit, the gap between the contacts becomes smaller and the entire voltage drop takes place across the pair of contacting surfaces. This phenomenon essentially forms a capacitance which is electrostatically charged upto that voltage. As the contacts come closer to each other, the field strength across the capacitor formed by the pair of contacting surfaces exceeds the breakdown strength of the air gap resulting in a spark.

In the present investigation, workpiece and the tool form the pair of contacting surfaces. As the tool moves closer to the workpiece during engagement, sparking occurs. During dis-engagement sparking takes place when the tool is withdrawn from the job.

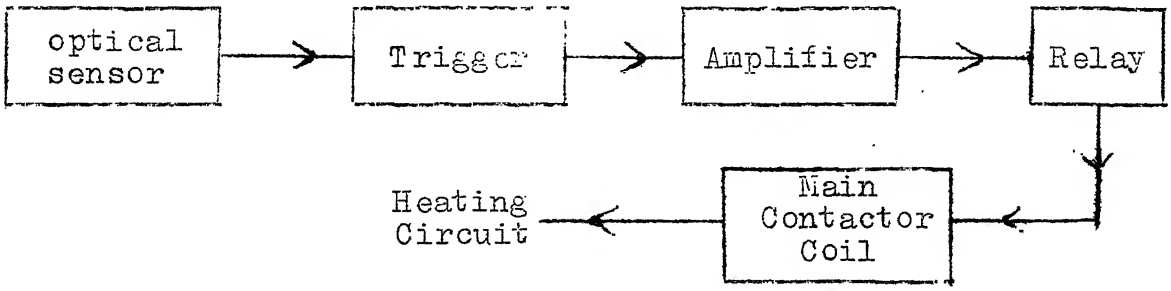
3.2 Block Diagram of Control Circuit :

In order to minimise the time gap between the instants of closing the heating circuit and engagement of the tool, an optical sensing technique is employed. To avoid sparking during tool engagement to the workpiece, the heating or main circuit is made operative following the engagement of the tool and the engagement of the tool is sensed through a light beam interruption. Therefore the system should have the following basic functional blocks.

a) An optical sensor.

b) A trigger unit operated by the optical sensor.

c) A power amplifier to drive the relay.



3.3 Description of the Relay Circuit :

The simplest yet most reliable optical sensor is a solid-state photo-diode. This is especially preferred for very low dark current (when light does not fall on sensor) and a voltage drop of low magnitude while passing a considerable amount

of current under illuminated condition. Such a photo-diode is used in the reverse biased condition for sensing the current that would flow following a photoelectric generation of carriers within it. Flow of these carriers constitute the current which in the absence of light becomes negligible. Therefore the sensor becomes a light dependent current source. This current level is to be compared for the illuminated and dark conditions for which an emitter coupled binary circuit is employed. Referring to Fig. 1, SI 100 is the photo-diode employed for the purpose and the current is fed into the schmitt or the emitter coupled binary circuit comprising resistances R_1 to R_6 and transistors Q_1 and Q_2. The operation of the circuit is as follows.

If a current is allowed to flow through R_1, the transistor Q_1 conducts and there is a current through resistor R_2. As a result, the voltage across R_4 and R_5 is reduced considerably and Q_2 remains in OFF state. The voltage between the base and emitter of Q_2 is negative under this condition. Thus there is no voltage drop across R_6 which is supplying the current between the base and emitter of the PNP transistor Q_3. Then Q_3 remains in OFF state and consequently Q_4 and Q_5 are deprived of their base currents. Therefore, Q_4 and Q_5 are also in OFF state and the relay is de-energised.

Now if the light beam incident on the photo-diode is interrupted by some mechanism, the transistor Q_1 is starved of

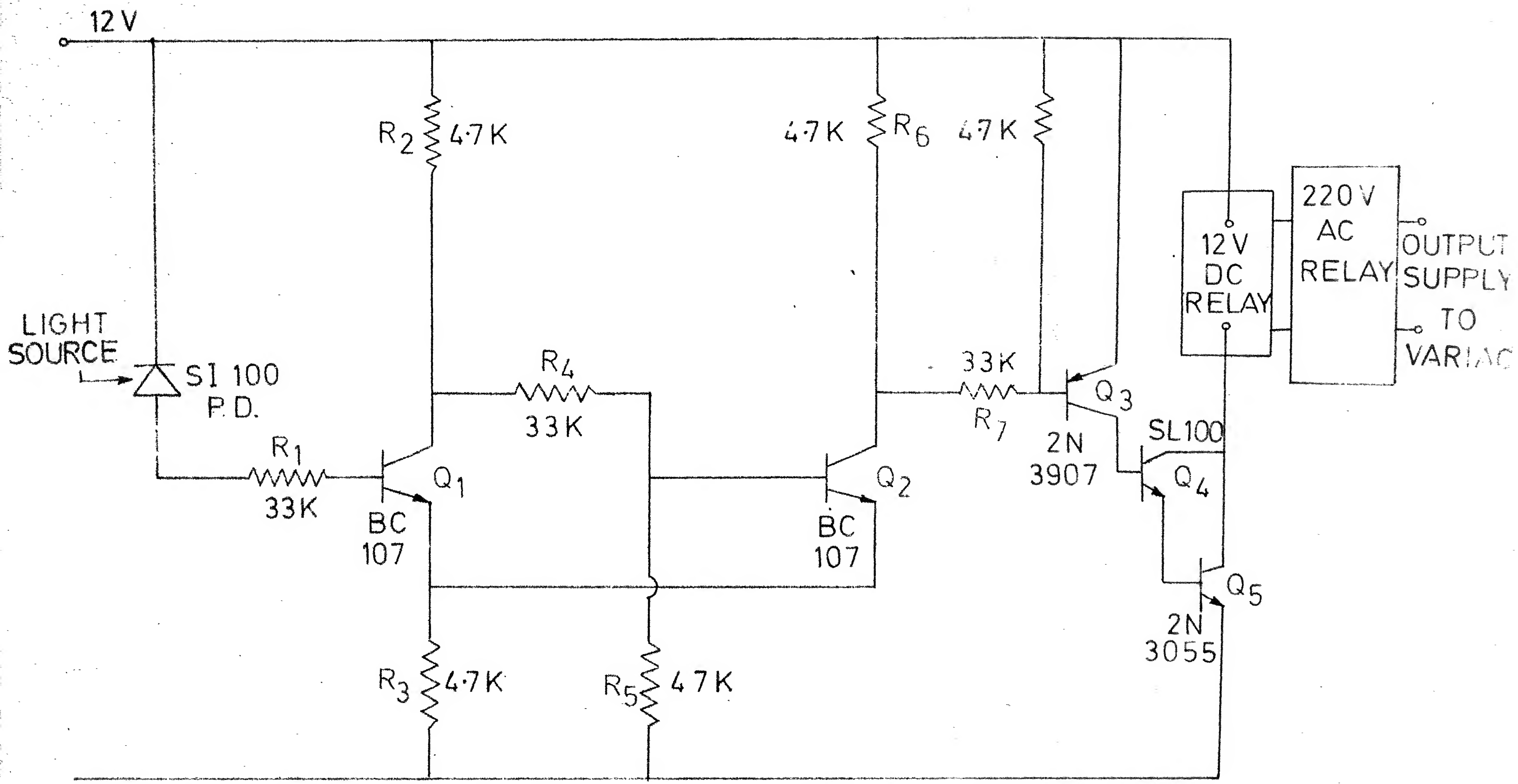


FIG. 1 LIGHT SENSITIVE RELAY CIRCUIT DIAGRAM

its current and Q_2 becomes ON due to a forward base emitter voltage drop across it. As Q_2 is ON, the transistor Q_3 is also in ON state due to the fact that there is a voltage drop across R_6 due to conduction in Q_2. Collector current of Q_3 flows as base current of Q_4 and the emitter current of Q_4 serves as the base current for Q_5. Thus Q_5 is made ON and the relay coil is energised.

Thus the relay operates from a light source. This relay is driven through a low voltage source and cannot be employed for the make or break of the main heating circuit. Another power contactor relay is employed whose coil is being driven from 220 Volts A.C. through the contacts of the low voltage relay. Therefore as the small relay is energised, the contactor coil also gets activated and the heating circuit is made ON through the contacts of the power contactor relay.

A capacitor is connected across the tool and workpiece to avoid sparking arising out of the sudden change in electromagnetic energy following withdrawal of the tool. The capacitor absorbs this energy in the process of changing to a voltage caused by the sudden interruption of current followed by the disengagement of the tool.

3.4 Design of the Electronic Control Circuit :

The controller drives an electromechanical relay coil whose rating is as follows.

Operating coil current = 500 mA

Operating coil voltage = 12 V

An NPN transistor switch driving the coil should have at least this minimum rating. The transistor selected for the purpose is 2N3055 whose specifications are as follows.

Collector emitter breakdown voltage = 90 V minimum.

Collector current = 11 Amp. maximum.

Common emitter current gain = 20 minimum.

$$\text{So, base current required} = \frac{\text{Collector load current}}{\text{Common emitter current gain}}$$

$$= \frac{500\ \text{mA}}{20} = 25\ \text{mA}.$$

For obtaining a base current of 25 mA, another transistor is used for cascading. The specification of the driven NPN transistor (SL 100) is as follows.

Collector emitter breakdown voltage = 60 V minimum

Common emitter current gain = 50 minimum

Collector current = 300 mA

$$\text{Thus the base current for this transistor} = \frac{25\ \text{mA}}{50} = 0.5\ \text{mA}$$

The two transistors, SL 100 and 2N3055 are connected as a Darlington pair. This pair is now being driven by a PNP transistor 2N3907 with a nominal current gain. The purpose is to provide a buffer between the schmitt trigger and the transistor

switch formed with Darlington pair. This transistor is used to minimise the loading effect on schmitt trigger. The base emitter resistance of this transistor is chosen to be 4.7 K, so that a slight amount of forward bias is provided onto it. The resistance in series with it's base may now be calculated. While the transistor Q_2 is ON, the base current of Q_3 flows through resistors R_7 and R_3. The voltage drop across R_6 and R_3 are made exactly equal for providing a reasonable hysteresis in the schmitt trigger circuit. Collector current for Q_2 is chosen as 1.5 mA. In that case,

$$R_3 + R_6 = \frac{12 - 0.2}{1.2} = 9.8 \text{ K}$$

As $R_3 = R_6$, therefore, $R_3 = R_6 = 4.7$ K is quite acceptable.

The value of R_7 should be so chosen that it becomes almost one order of magnitude higher than R_6 because current flows to Q_3 through R_6 and R_7. R_7 is chosen to be 33 K.

The schmitt trigger emitter voltage is therefore given by $\frac{12 - 0.2}{9.4} \times 4.7 = 5.9$ volts and this voltage is dropped across R_3. The resistances R_4 and R_5 are calculated from the base voltage of Q_2. The base voltage for Q_2 should be equal to $5.9 + 0.6 = 6.5$ V which is the voltage across R_5.

$$\text{Base current required by } Q_2 = \frac{1.2}{50} = 240 \ \mu\text{A}$$

So the thevenin resistance of R_4R_5 combination allow this current.

Thus the conditions are,

$$\frac{6.5\ (R_4 + R_5)}{R_4 R_5} \geqslant 240 \text{ X } 10^{-6} \quad \text{and}$$

$$\frac{R_5}{R_4 + R_5} \text{ X } 12 \geqslant 6.5$$

These above two equations if solved for equality given R_4 = 50 K and R_5 = 59 K. To ensure more safety of switching, R_5 is made 47 K and R_4 is chosen to be 33 K. This again is checked as follows.

The collector resistance of Q_1 should be at least one order less than the value of $(R_4 + R_5)$ as the latter loads this resistance. A similar value of 4.7 K is chosen accordingly. While the Q_1 is ON, the voltage drop across the collector should not be able to turn ON Q_2 and this is a check for the satisfactory operation of the trigger circuit and the viability of the previous choice of R_4 and R_5.

The voltage at the collector of Q_1 while it is ON is equal to $\frac{12 - 0.2}{4.7+4.7}$ X 4.7 + 0.2 = 6.1 volts. Now the voltage across R_5 = $6.1 \text{X} \frac{47}{80}$ = 3.6 volts. Therefore the transistor Q_2 has a base voltage of 3.6 volts whereas the emitter voltage is 5.9 volts. Thus the transistor is under cut-off condition.

Base drive required for Q_1 is the same as that for Q_2 because collector resistances are same. So, a series resistance

of 33 K in the base is sufficiently small to allow the diode voltage to cause a base current through Q_1.

The photo-diode is chosen depending on its reverse breakdown voltage. The supply voltage being 12 volts, the breakdown voltage must exceed this value. SI 100 is chosen to meet this requirement.

3.5 Mechanism for the light beam interruption :

The relay circuit is made in such a way that the heating circuit will be in ON state when the light beam (pencil beam) falling on the photo-diode gets blocked. Thus a mechanism should be employed such that light beam does not fall on the diode when the tool moves to its predetermined depth of cut. The mechanism is shown in Fig. 2.

Two metal plates are mounted parallel on to a vertical plate and this unit is fixed by screws to the cradle of the lathe. The light sensitive diode and sources are fixed on the parallel plates facing each other. A voltage of 9 V. d.c. is supplied to energise the source through a toggle switch. Another thin metal plate moves in the gap between the two parallel plates which are mounted on the cradle. The purpose of the thin plate is to act as an obstruction, to interrupt the light beam for a required depth of cut. The position of the beam interruption can be adjusted to the depth of cut accordingly by adjusting the lock nuts provided with the unit.

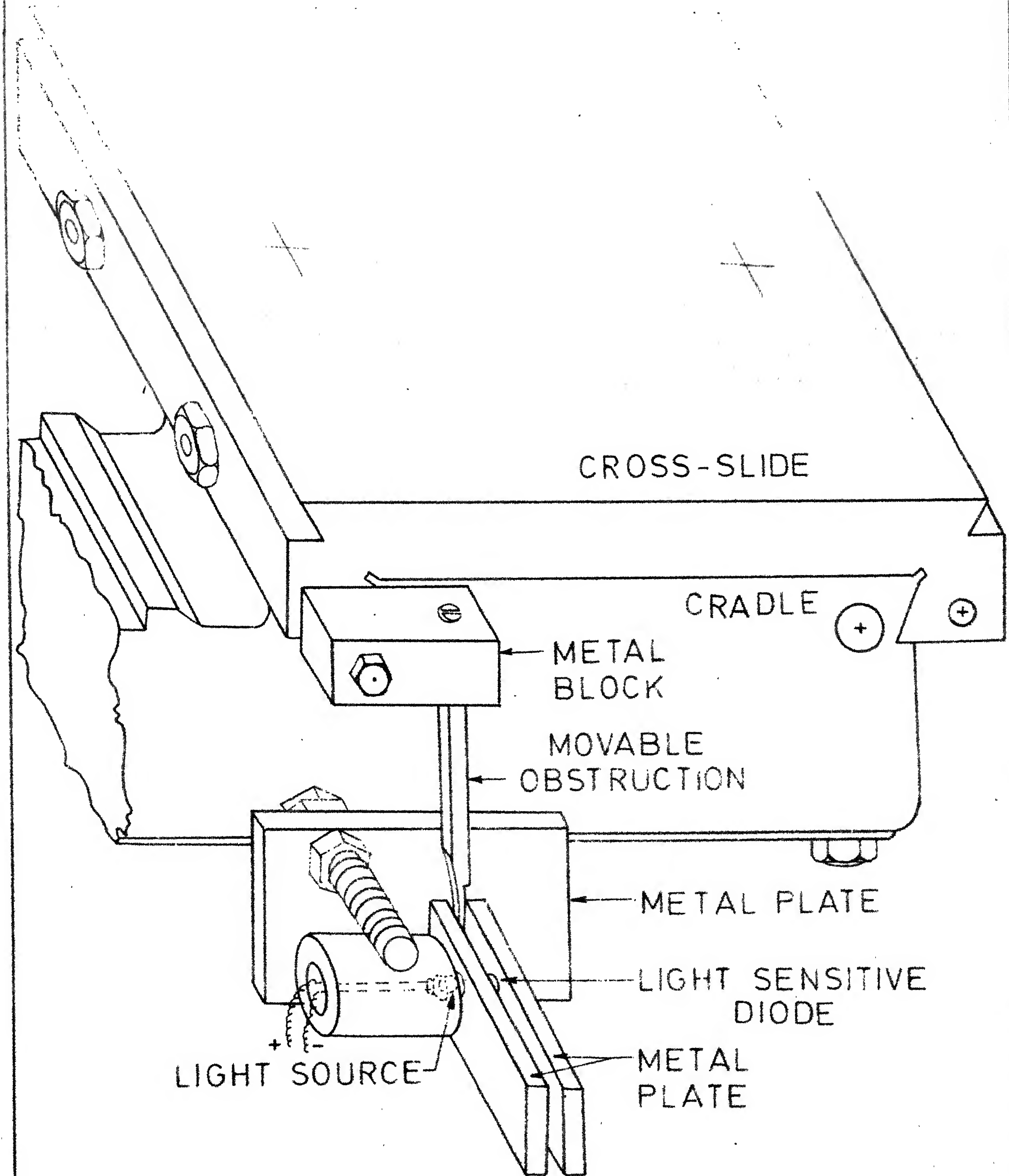


FIG.2 MECHANISM FOR LIGHT BEAM INTERRUPTION FOR RELAY CIRCUIT

CHAPTER - 4

EXPERIMENTAL SET-UP

4.1 Experimental Set-Up :

The experimental set-up used to carry out hot machining experiments by electric-resistance heating, was designed and fabricated by Chaudhary [31] and Sachdeva [32]. The schematic diagram of the experimental set-up is shown in Fig. 3.

4.2 Workpiece Heating Technique :

In the present experiment, electric-resistance heating technique is adopted. A high alternating current upto 250 amperes is passed through the chip-tool interface by using a step down transformer across the tool and workpiece. The input voltage to the transformer is controlled by using a 15 Amperes variac, so that the current to the chip-tool interface and therefore the heating effect can be varied. The connection between the transformer and workpiece is achieved by using graphite impregnated copper brushes. The brushes are mounted on a steady-rest and they are spring loaded to ensure constant contact between the brushes and the workpiece during its rotation. The high alternating current low voltage output of the transformer is carried by cables having 600 amperes carrying capacity to copper-graphite brushes. The workpiece is properly insulated from the lathe body.

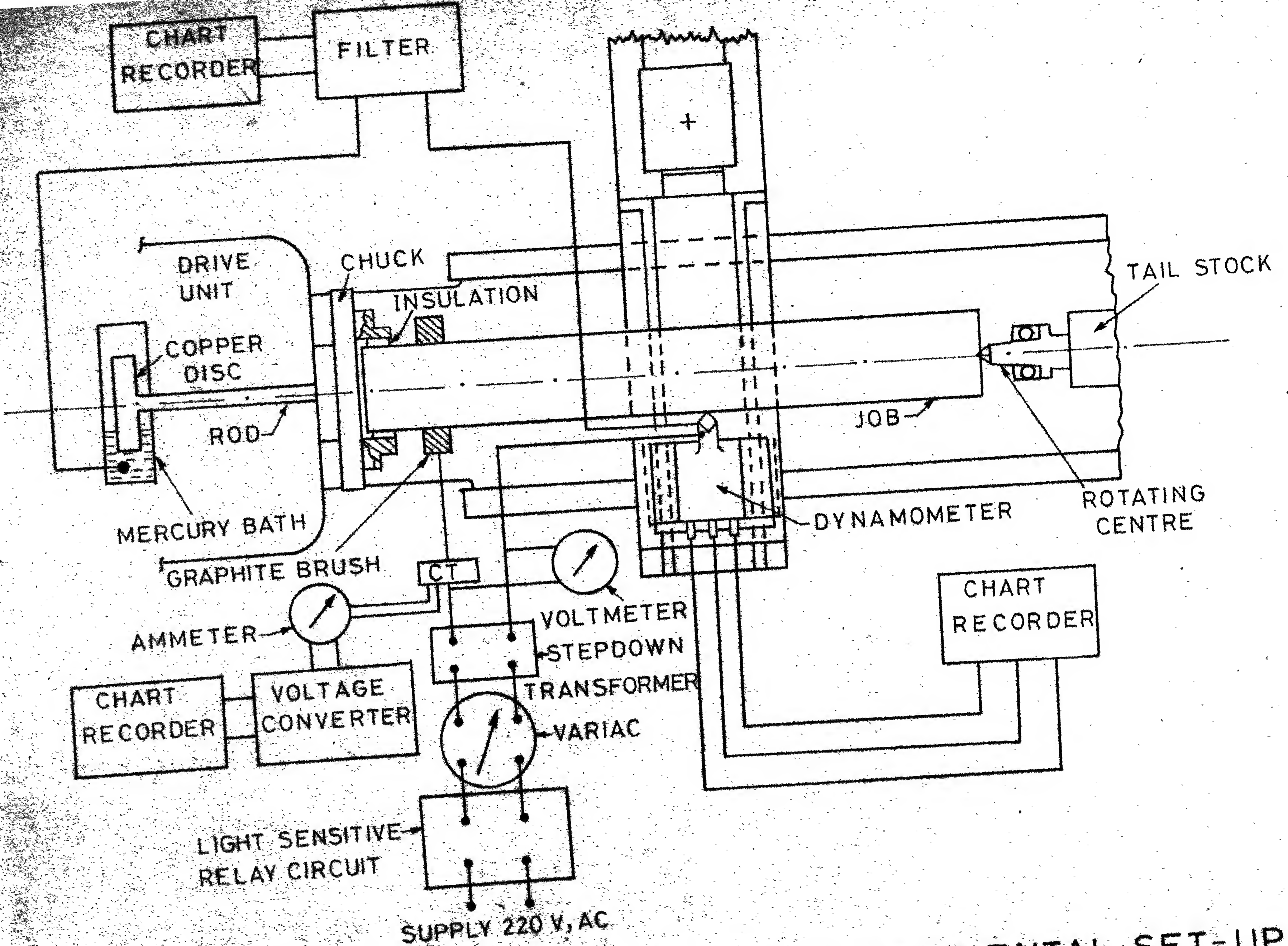


FIG. 3 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP

The tool is connected to the negative terminal and it is also insulated from the dynamometer. An avometer is used to check proper insulation.

A current transformer having ratio of 1000/5, is used for measuring the current flowing through the cables. The secondary of the transformer is connected to a voltage converte circuit for recording the current. A voltmeter of 0-5 volts (A.C.) range is used to measure the voltage at which the curren is being supplied.

4.3 Three Dimensional Lathe Tool Dynamometer :

A three dimensional octagonal ring dynamometer [33] is used for measuring Feed Force. The dynamometer is enclosed in a brass box to ensure protection from chips during machining The dynamometer is bolted on a holding platform and mounted on the compound slide of the lathe.

The calibration curves for feed force and radial force are shown in Figs. 4 and 5 respectively. The dynamometer has a cross sensitivity of less than 5 percent in the two directions.

4.4 Temperature Measurement :

The temperature at the tool tip in the present study is measured by Tool-Work thermocouple technique used by Sachdeva [32]. Other methods [34] to measure the temperature

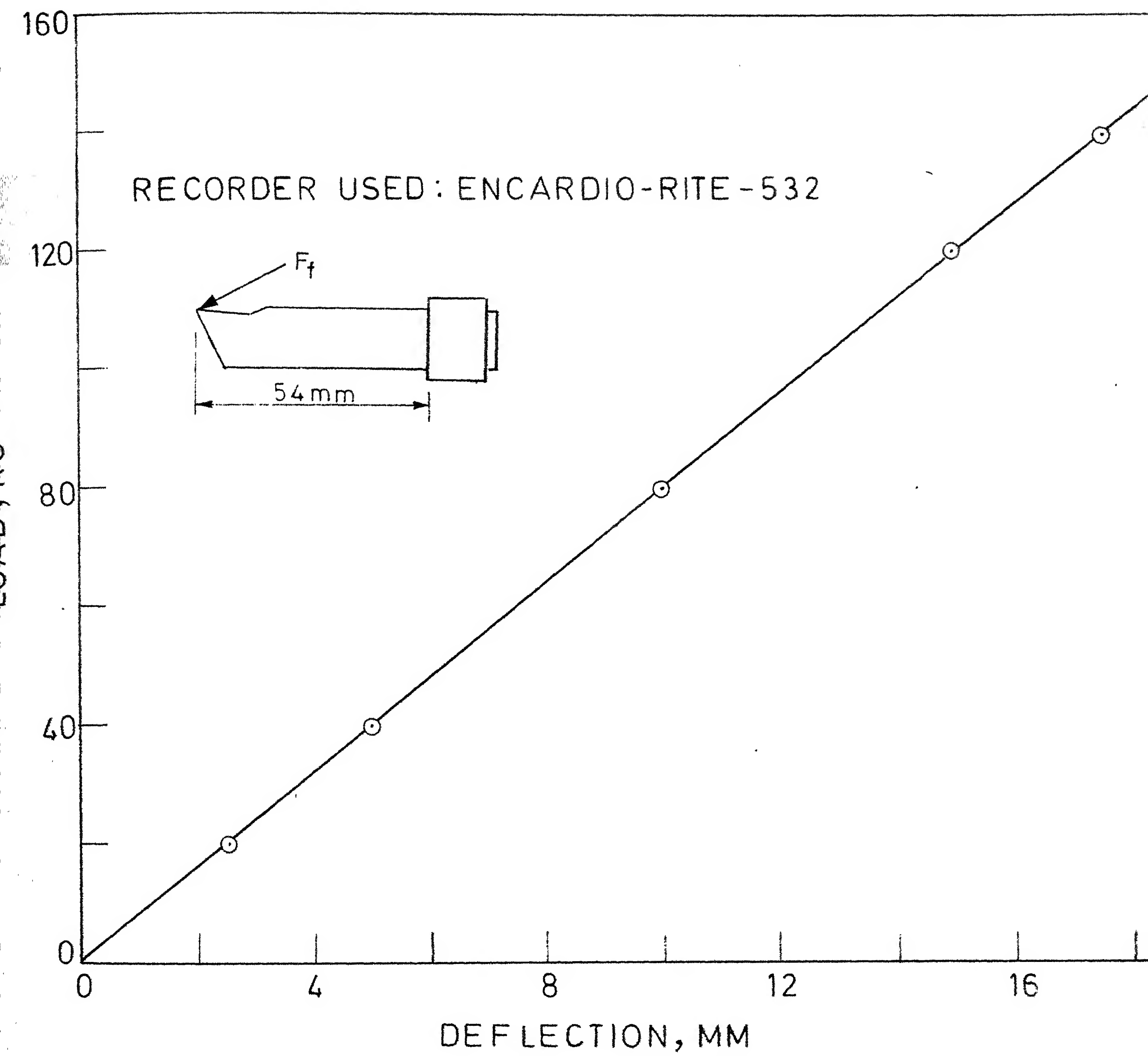


FIG. 4 CALIBRATION CURVE FOR FEED FORCE
SENSITIVITY 2 MILLIVOLT = 1 CM AND SUPP
VOLTAGE 12 VOLTS

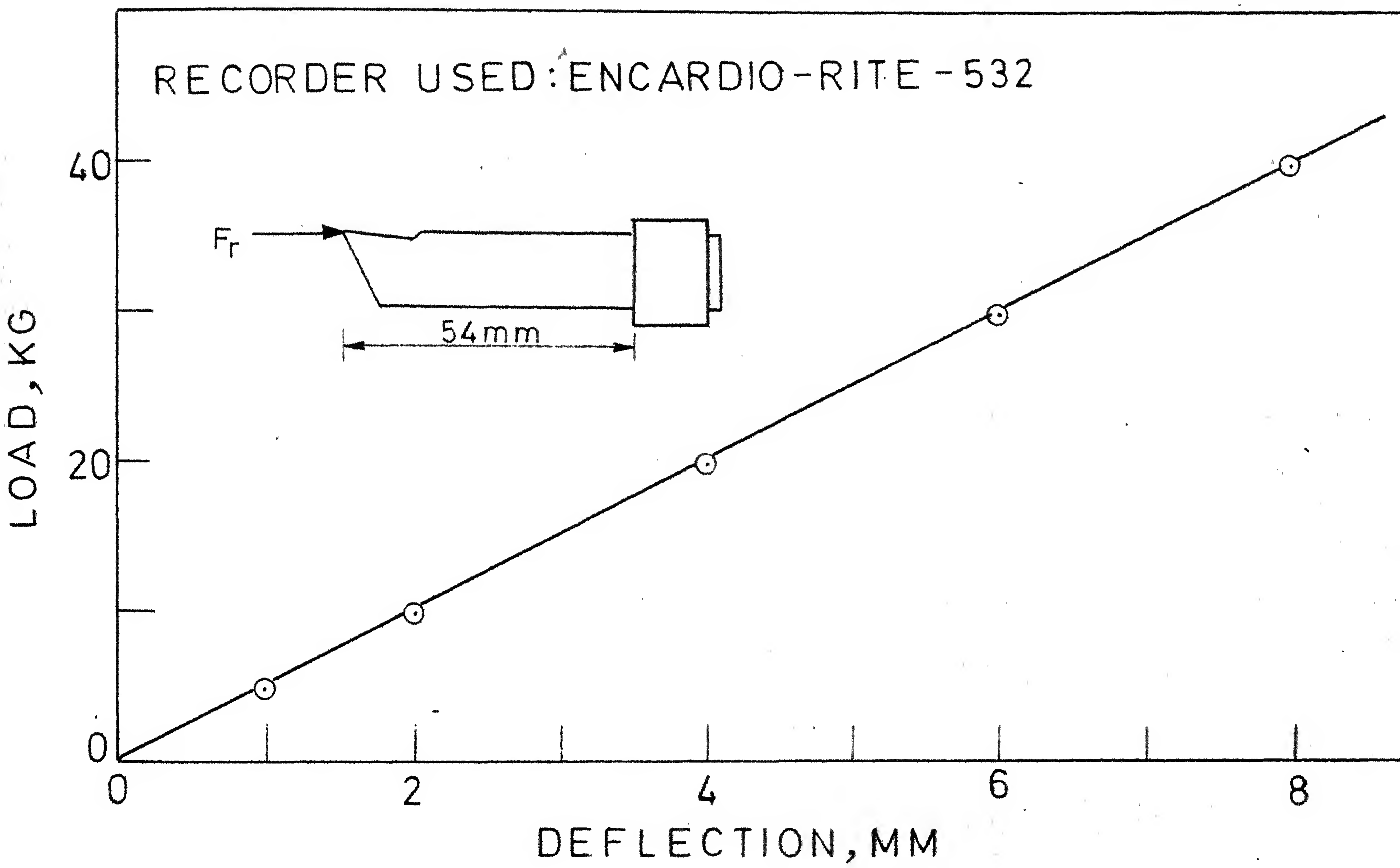


FIG.5 CALIBRATION CURVE FOR RADIAL FOR
AT SENSITIVITY 1 MILLIVOLT = 1 CM AND
SUPPLY VOLTAGE 12 VOLTS

are Optical pyrometer, Radiation pyrometer, Resistance pyrometer and Indirect calorimetric technique. They suffer from (1) Slow speed of response, (2) Indirectness of the measurement and (3) Geometrical difficulties in application.

The tool-work thermocouple method employs the tool and work material as the two elements of the thermocouple. The tool-work contact area serves as a hot junction in a thermo-electric circuit and the e.m.f. generated is proportional to its temperature. A copper disc is fixed at the end of a rod secured to one end of the workpiece. The copper disc is rotating in a mercury bath to make a firm electrical contact. The e.m.f. produced is fed to a chart recorder through a filter. The temperature is read from e.m.f. and temperature calibration curve shown in Fig. 6.

One end of the electrical connection of the heating circuit and the thermal e.m.f. circuit meet at the tool which may cause errors in the e.m.f. due to the supply voltage at 50 HZ. Since in the present work, frequencies greater than 60 HZ are not expected, a low pass filter, designed by Raghuram [35], is used to suppress the frequencies below 60 HZ to a designed value of cut-off frequency of 0.03 HZ. Thus the temperature (D.C.E.M.F.) at the cutting tool point can be measured correctly.

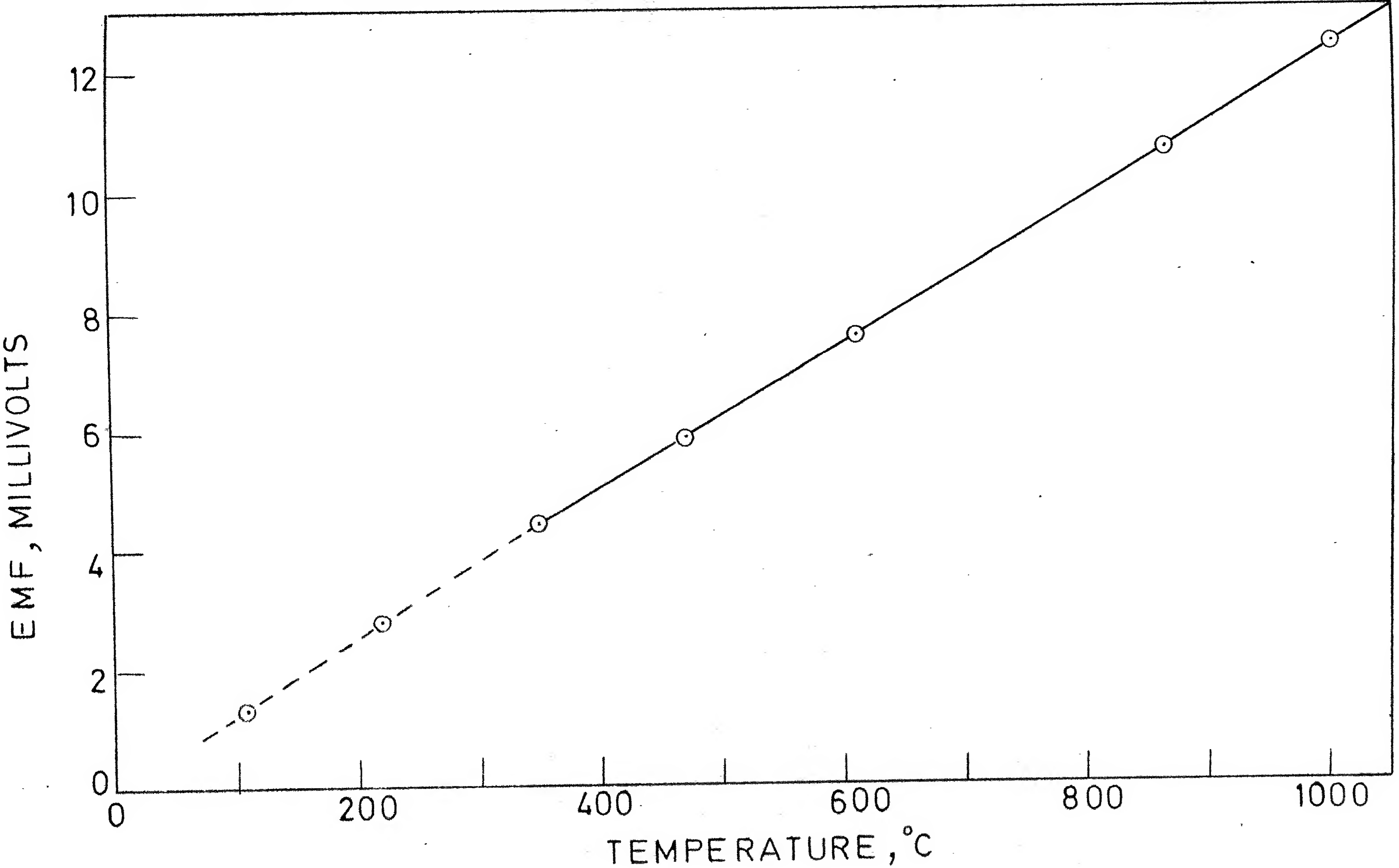


FIG. 6 TEMPERATURE CALIBRATION CURVE FOR EN 24 STEEL-WC THERMOCOUPLE [32]

4.5 Heating Current Recording :

There are two alternatives viz. a shunt or a current transformer to measure/record high alternating current. The former provides a voltage drop proportional to the current without any electrical isolation whereas the latter satisfies both the requirements. This is the basic reason of employing a current transformer to measure/record the heating current. A conventional portable A.C. ammeter of 0-5 ampere range is used to measure the heating current. The current transformer secondary is loaded with the ammeter and a non-inductive resistance of 0.4 ohm. as shown in Fig. 7. The voltage drop across the resistance is half wave rectified and filtered with the help of a diode - BY 127 and a capacitor of 10 μF. The steady D.C. voltage so obtained is fed to a recorder for continuous recording of the heating current during the machining operation. The rectifier voltage drop, being negligible at the maximum heating current, does not introduce any appreciable error in the proportionality of the D.C. voltage with the heating current. The filtering is done with a moderate time constant such that the ripples are not predominant at the output, even though any change in the heating current showed an instantaneous change in the voltage fed to the recorder.

In order to calibrate the recorder, the tool is made to contact the workpiece firmly and a predetermined current shown

by an A.C. ammeter is passed through the circuit. The calibration curve for the heating current is shown in Fig. 8.

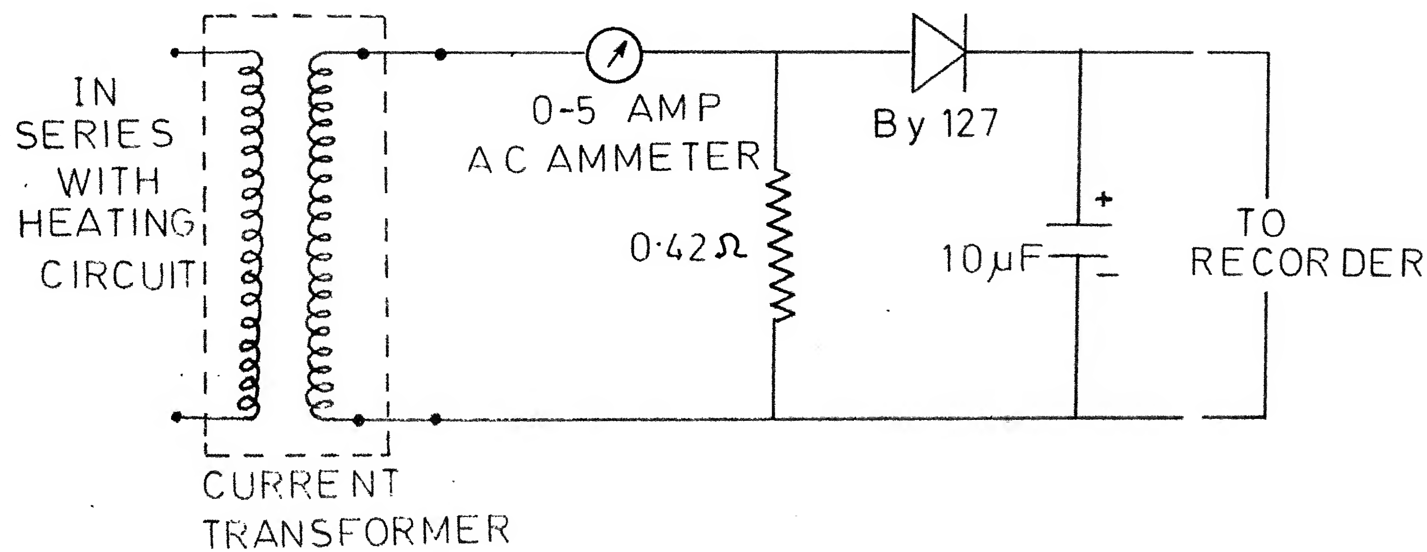


FIG.7 VOLTAGE CONVERTER CIRCUIT

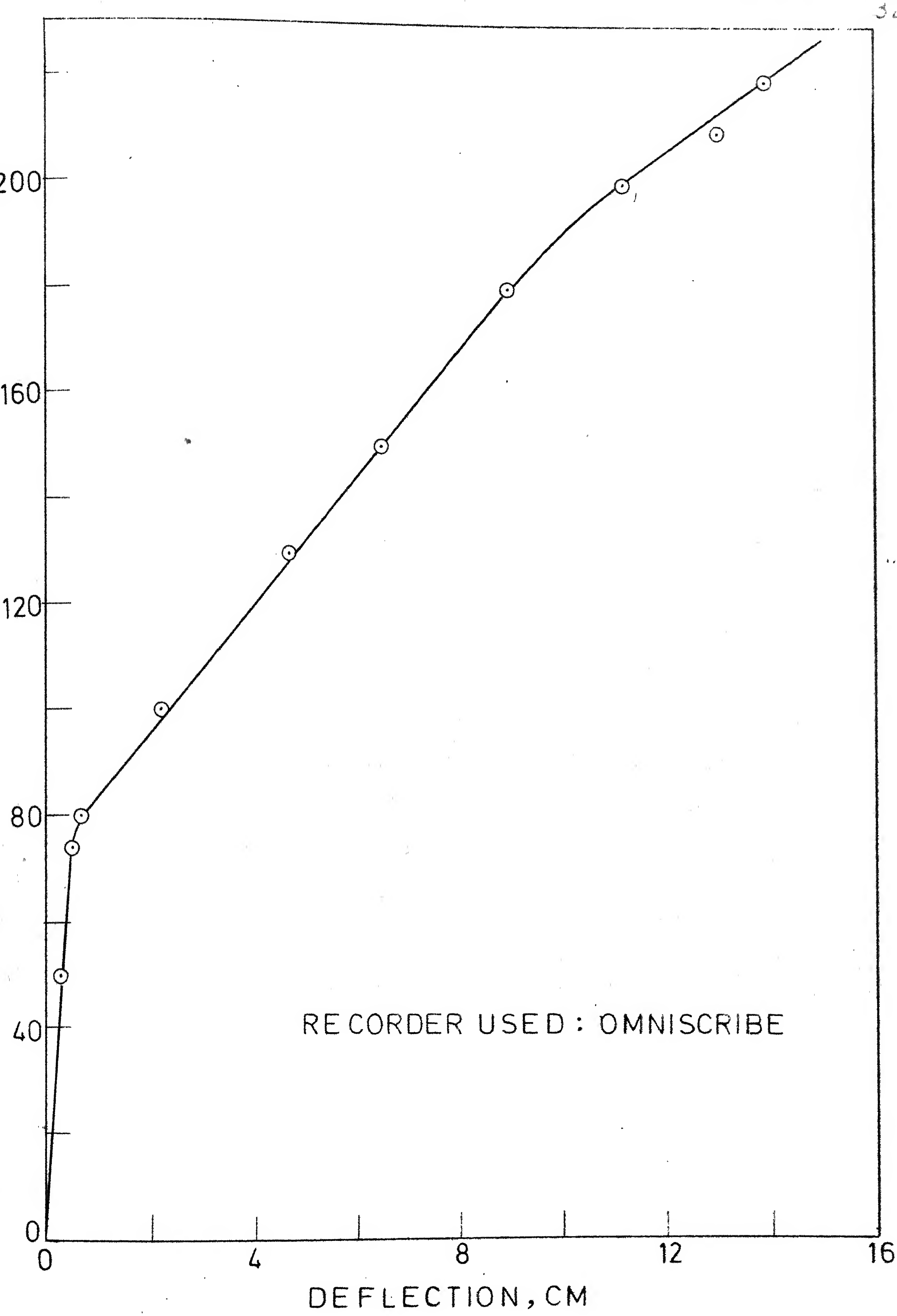


FIG. 8 CALIBRATION CURVE FOR HEATING CURRENT AT SENSITIVITY 1 VOLTS FULL SCALE DEFLECTION

CHAPTER - 5

EXPERIMENTAL INVESTIGATION

5.1 General :

The major problem encountered in electric-resistance heating is the occurence of sparking during engagement and dis-engagement of the cutting tool. Barrow [3] reported that the sparking damage the clearance face of the tool and suggested the use of a relay to avoid sparking. In the present investi-gation, experiments are performed in two conditions, a) when relay is used and b) when relay is not used. In the latter condition sparking is allowed to occur at the engagement and disengagement of the cutting tool.

5.2 Instrumentation :

Fig. 3 shows the schematic diagram of the experimental set-up which comprised the following instrumentation.

a) Electric-resistance heating circuit.

b) Light beam sensitive relay circuit.

c) Force measurement circuit.

d) Temperature measurement circuit.

e) Heating current recording circuit.

The details of all the circuits are discussed in previous chapters. The feed force and temperature are recorded on a four channel 'Encardio-rite-532' chart recorder. The heating current is recorded on a strip chart 'Omniscribe' recorder.

Length of flank wear is measured by a tool-room microscope having least count of 0.002 mm.

Surface roughness is measured with the help of a profilometer.

5.3 Experimental Procedure :

All the machining tests are carried out on a 10 H.P., H.M.T. LB-17 lathe. The workpiece of En-24 alloy steel round bar of 75 mm. diameter and one meter long is used for machining. En-24 alloy steel is selected since its machinability is low [36]. The Coromant Carbide 194.4 - 1623 - S - 4 throwaway tips having geometry of 0, 6, 11, 5, 15, 15, 1.2 are used as cutting tools. The properties of En-24 steel and carbide tool are given in Appendix A.

The workpiece is machined for a sufficient length to obtain spark free contact of brushes. Finally machining zone of length 650 mm. of the workpiece is turned to a diameter of 70 mm. for performing the experiments.

The following sets of experiments are conducted to study the effects of heating current on feed force, chip-tool interface

temperature, flank wear and surface finish in both the conditions of using relay and without using relay.

a) Heating current is varied from 0 to 250 amperes in steps of 50 amperes while keeping cutting speed at 97 m/min, feed at 0.1 mm/rev., depth of cut at 1.5 mm and time of cut of 30 seconds. A new cutting edge is provided for each test. Feed force, interface temperature and heating current are continuously recorded. Flank wear and surface finish are measured after each test while the job is still on the machine. Figs. 9 to 12 show the results of heating current test.

b) Tool wear tests are carried out at a heating current of 150 amperes as previous investigation by Dey [33] showed that optimum current range for maximum tool life lies between 100 and 150 amperes. Cutting speed, feed, depth of cut and time of total machining under both the conditions of using relay and without using relay are kept at 166 m/min., 0.1 mm/rev., 1.5 mm. and 150 seconds respectively. Feed force, interface temperature and heating current are continuously recorded. Flank wear and surface roughness are measured after every 30 seconds of machining in both the conditions of using relay and without using relay. The results of tool wear tests are shown in Figs. 13 to 16.

c) Tool life tests are performed using relay for heating current of 0 to 150 amperes in steps of 50 amperes. Cutting speed is kept in the range of 110 to 130 m/min. while keeping

feed at 0.1 mm/rev. and depth of cut at 1.5 mm. Fig. 17 represents tool life tests for the heating current of zero, 50, 100 and 150 amperes. The values of tool life for the heating current of 100 and 150 amperes are compared with those of the experimental results of Dey [33]. It may be noted that Dey carried out experiments by avoiding sparking manually.

5.4 Experimental Results and Discussions :

5.4.1 Variation of Feed Force and Surface Roughness with Heating Current :

Fig. 9 represents the behaviour of feed force with heating current at constant cutting speed of 97 m/min. It shows that the decrease in the feed force is of the order of 14 percent upto a heating current of 250 amperes in the case of machining using relay whereas the order of reduction for same cutting conditions is only 7 percent in the case of without using relay. The decrease in the feed force resulted from the reduction in yield strength of the material with increasing heating current. This result agrees with the findings of other investigations. It can also be seen from Fig. 9 that the feed force is higher for the case of without using relay. Sparking damage the clearance face of the tool which causes increase in feed force. This increment in feed force increases as the heating current increases.

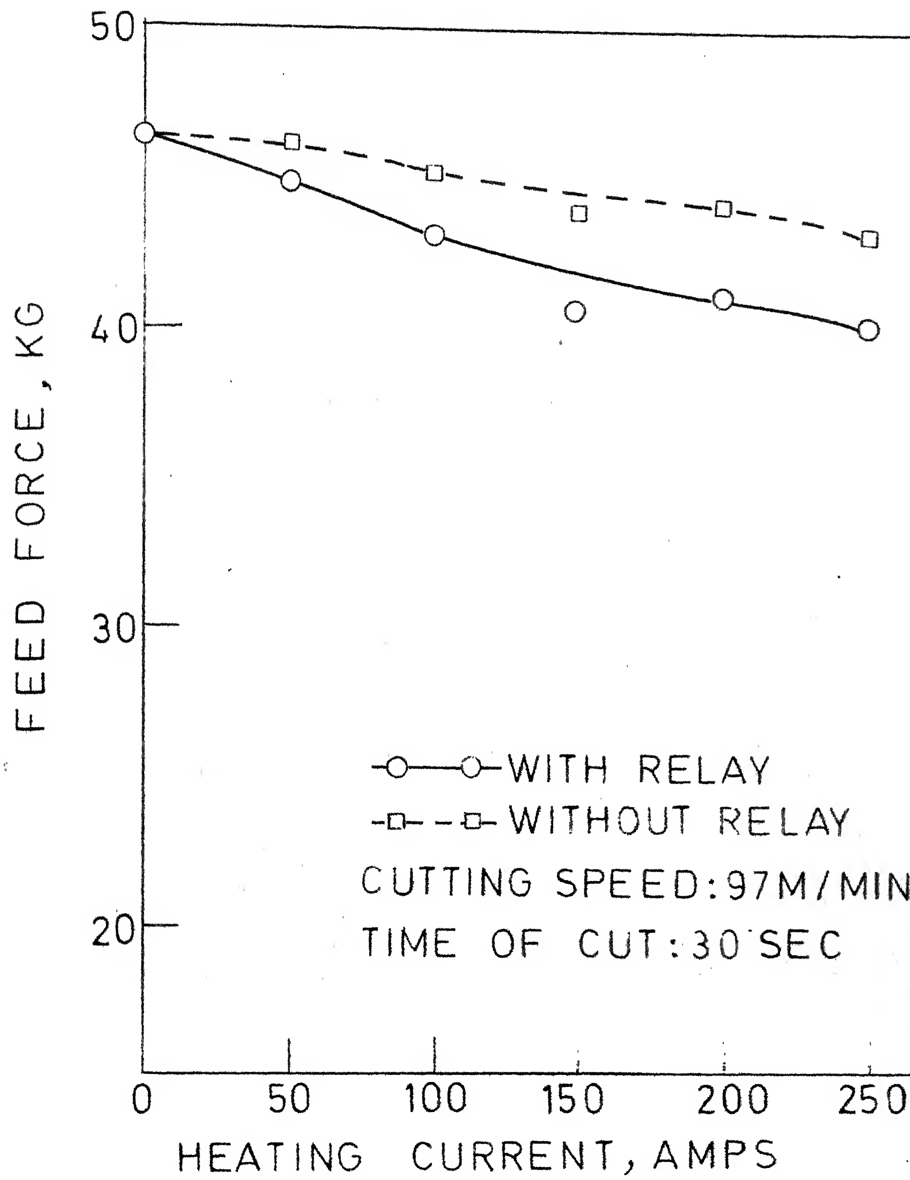


FIG. 9 VARIATION OF FEED FORCE WITH HEATING CURRENT

Fig. 10 shows the variation of surface roughness with heating current at a constant cutting speed of 97 m/min. In the case of using relay the surface roughness decreases with the increase in heating current because of improvement in the chip formation process due to reduced shear strength of the material. In case of machining without using relay, the surface roughness is much higher than that obtained under the condition of using relay. Thus the use of relay improves the surface finish tremendously.

5.4.2 Variation of Flank Wear with Heating Current :

Fig.11 shows the variation of the length of flank wear with heating current at a cutting speed of 97 m/min. For the condition of using relay, the length of flank wear decreases upto a heating current of 150 amperes and then increases with further increase in heating current. This behaviour resulted from the combined effects of cutting forces and chip-tool interface temperature on tool wear. Decrease in cutting forces with an increase in heating current reduces tool wear but increase in interface temperature with further increasing current dominates over other factors and thus causes tool wear to increase beyond an optimum value. From Fig. 11, it can be said that minimum tool wear is achieved in the current range of 100 to 150 amperes which tallies with the investigation of Dey [33]. Under the condition of machining without using relay, the optimum current

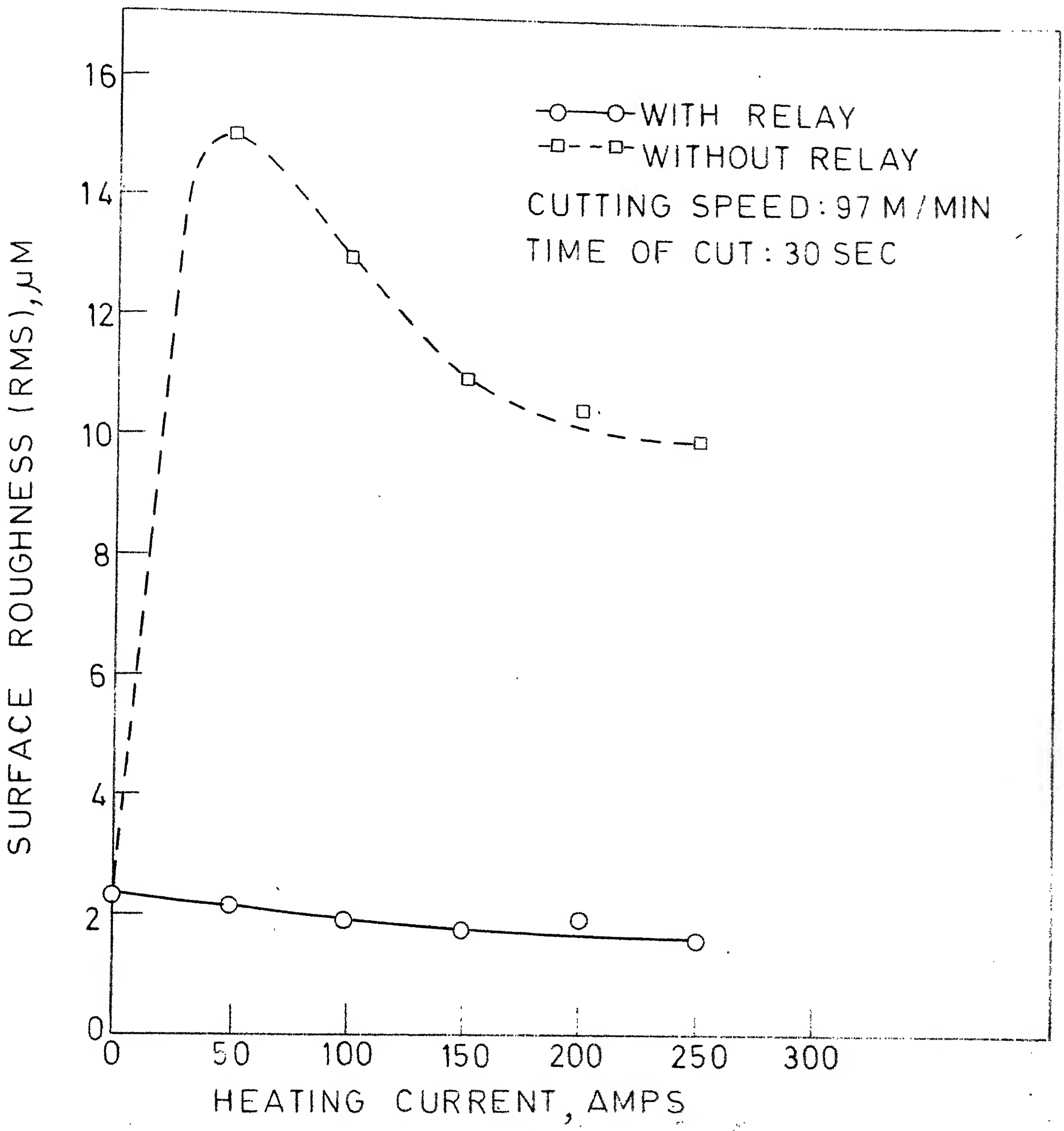


FIG.10 VARIATION OF SURFACE ROUGHNESS WITH HEATING CURRENT

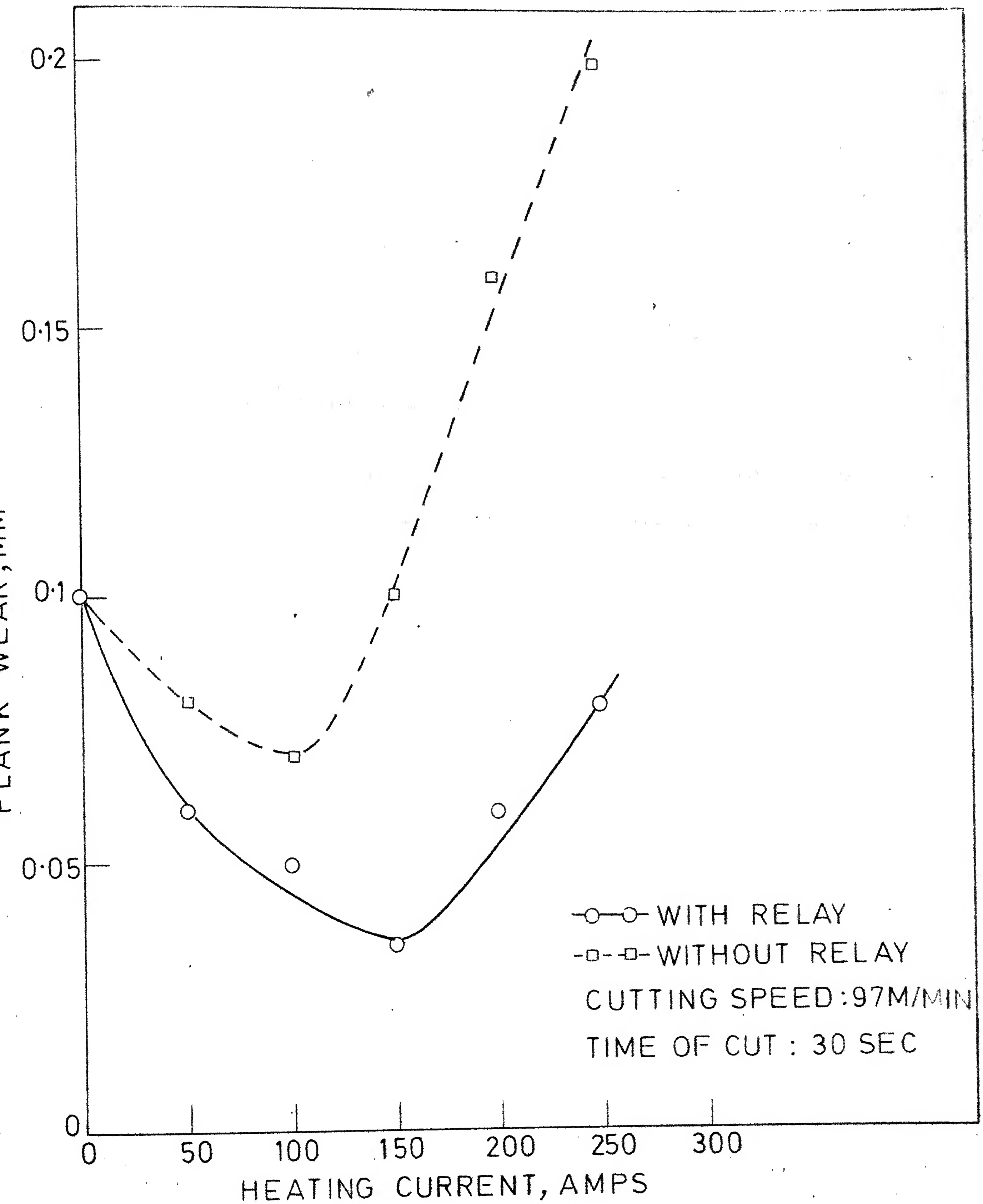


FIG.11 VARIATION OF FLANK WEAR WITH HEATING CURRENT

range changes from 100 - 150 amperes to 50 - 100 amperes corresponding to minimum tool wear. Flank wear values are much higher if the relay is not used.

5.4.3 Variation of Tool-Chip Interface Temperature with Heating Current :

Fig. 12 represents the variation of interface temperature with heating current at a cutting speed of 97 m/min. The increase in temperature is found to be linear with the increase in heating current and there is hardly any change in temperature in the two cases of machining using relay and without using relay.

5.4.4 Variation of Flank Wear with Time at 150 amperes :

Fig. 13 represents the variation of flank wear with time for heating current of 150 amperes and cutting speed of 166 m/min. It is seen that the length of flank wear varies linearly with time after an initial rapid wear for about 30 seconds. In case of machining without using relay, flank wear is more than that obtained under the condition of machining using relay. Thus use of relay results in improvement in tool life.

5.4.5 Variation of Feed Force, Surface Roughness and Tool-Chip Interface Temperature with Flank Wear :

Figs. 14 to 16 represent the variation of feed force,

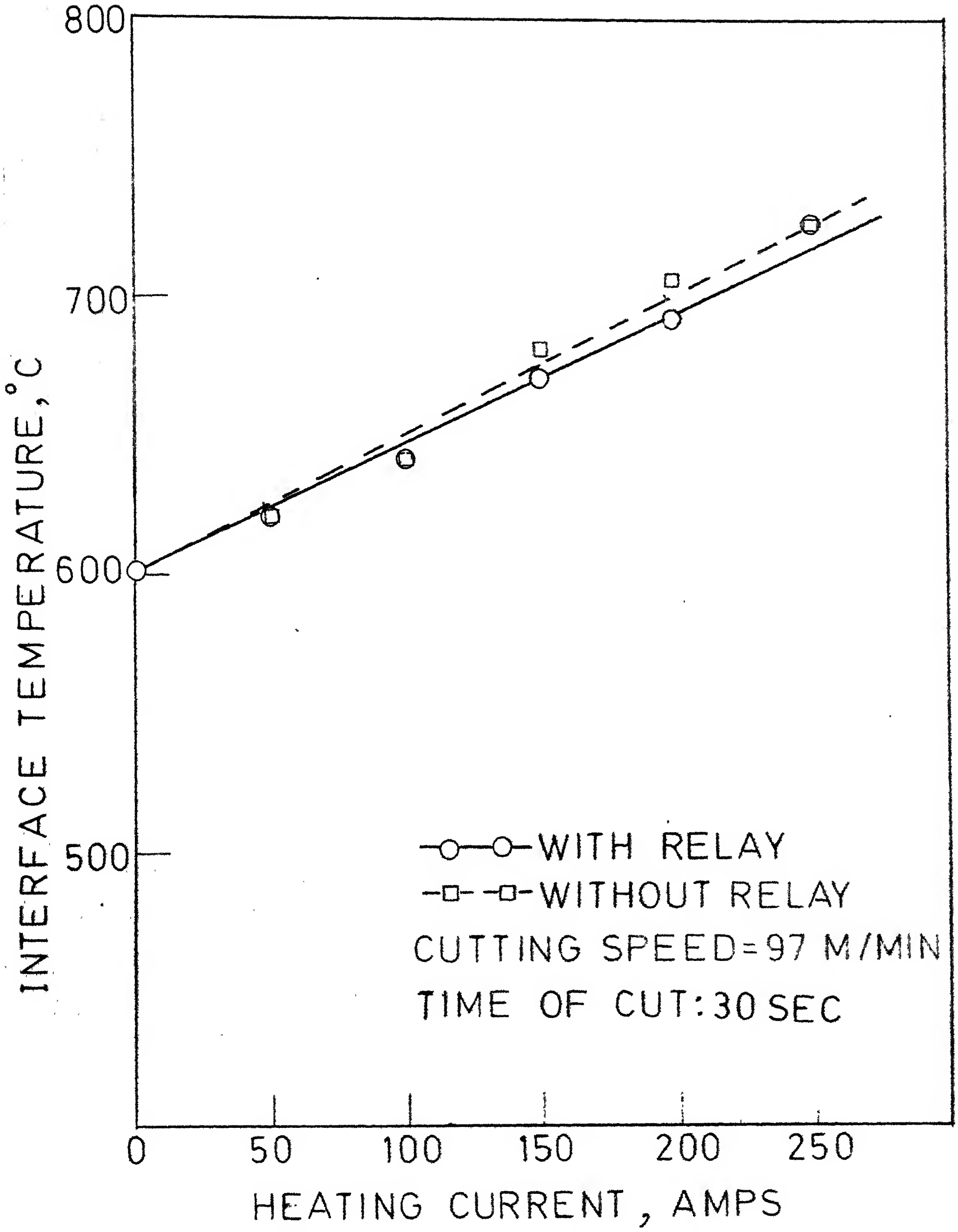


FIG.12 VARIATION OF TOOL CHIP INTERFACE TEMPERATURE WITH HEATING CURRENT

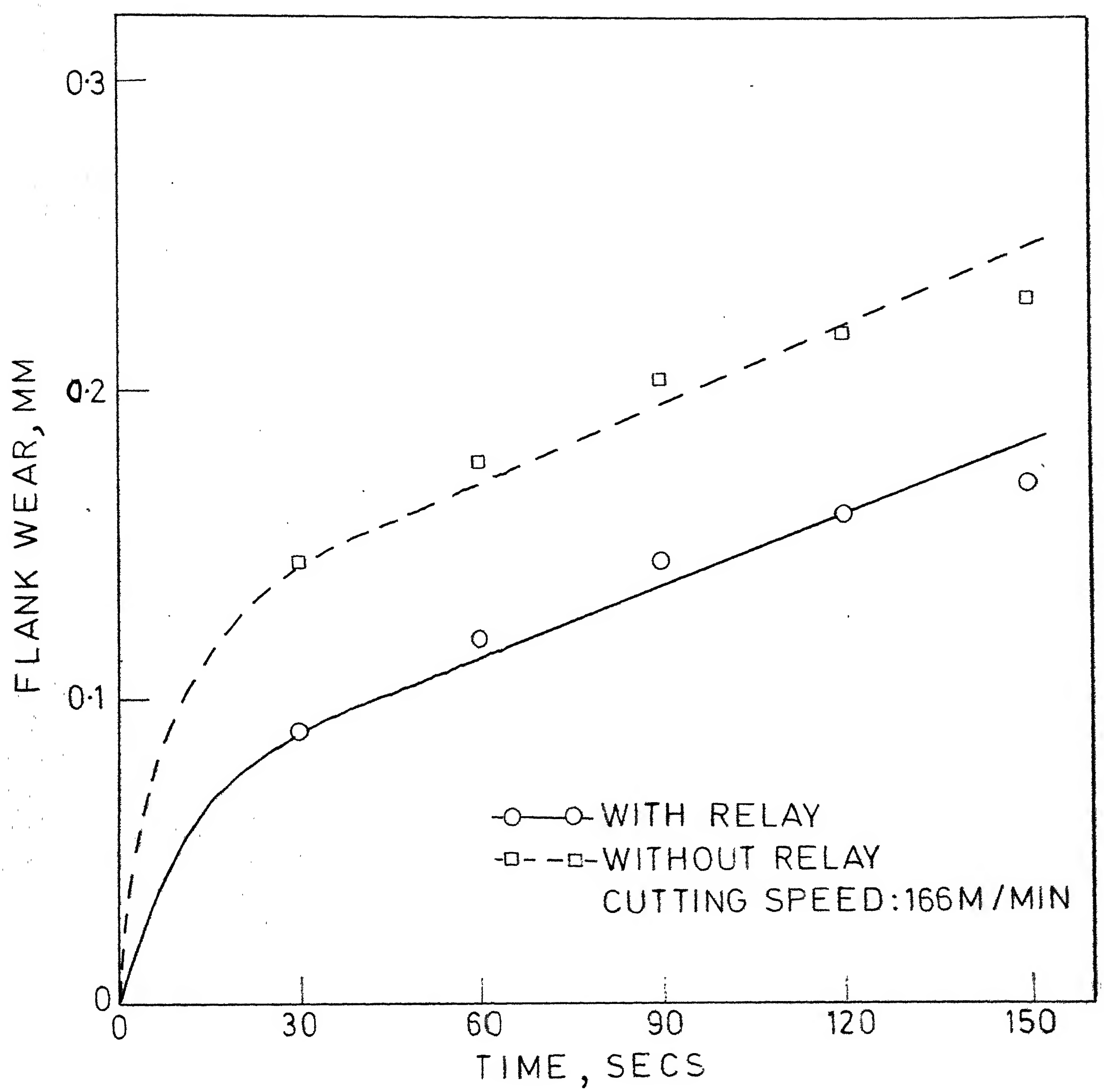


FIG.13 VARIATION OF FLANK WEAR WITH TIME AT 150 AMPS

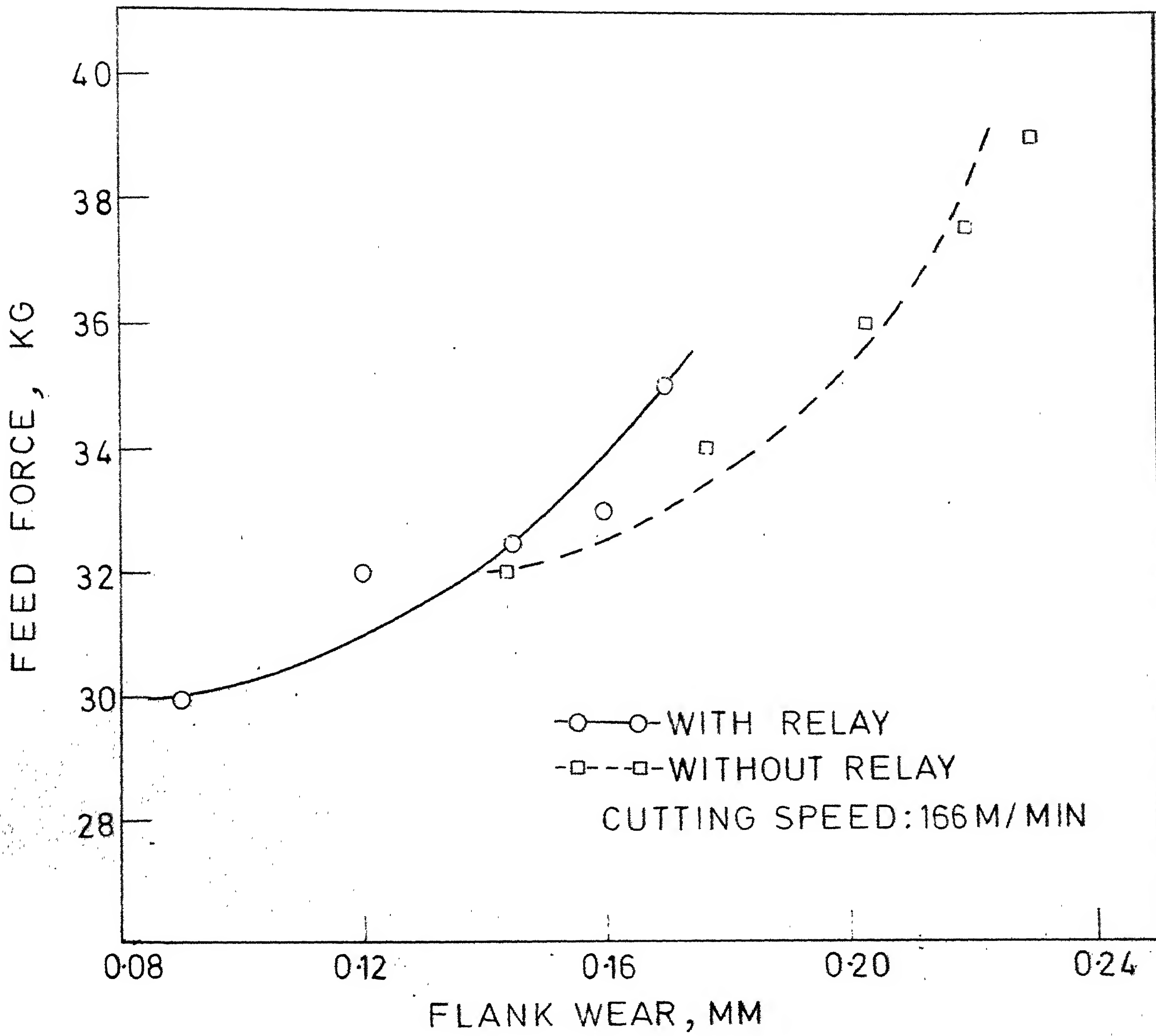


FIG.14 VARIATION OF FEED FORCE WITH FLANK WEAR AT 150 AMPS

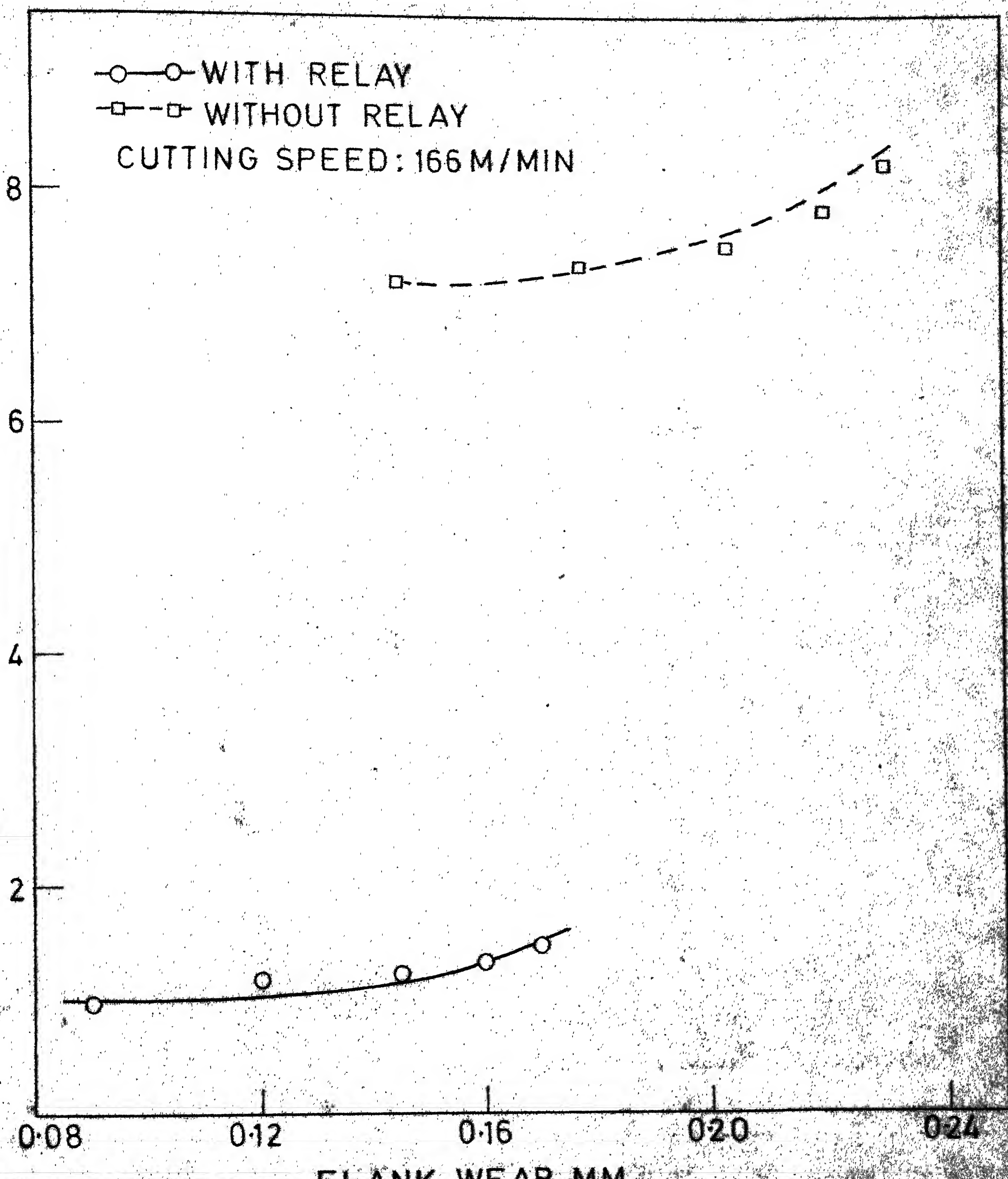


FIG.15 VARIATION OF SURFACE ROUGHNESS WITH FLANK WEAR AT 150 AMPS

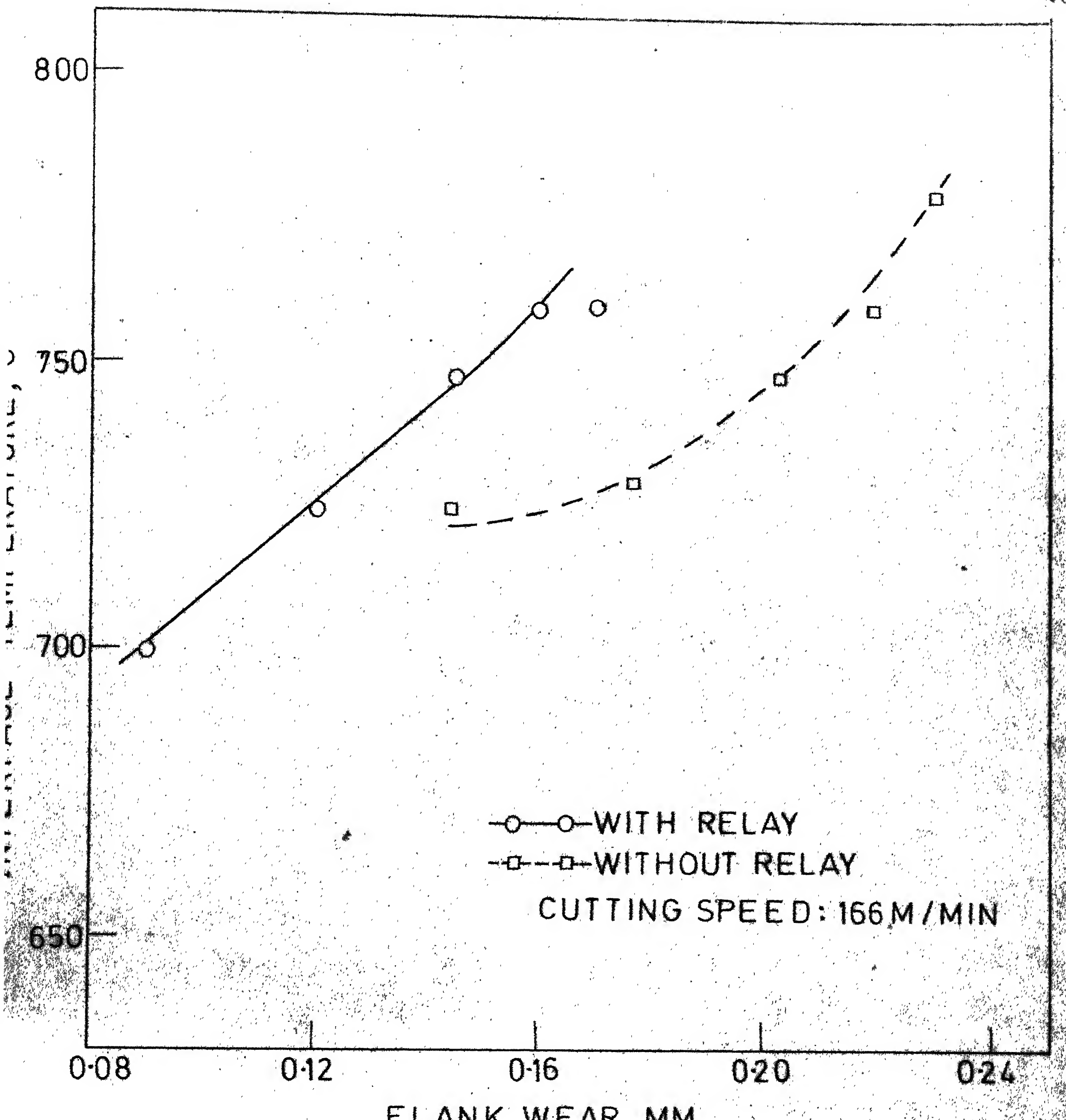


FIG.16 VARIATION OF TOOL-CHIP INTERFACE TEMPERATURE WITH FLANK WEAR AT 150 AMPS

surface roughness and interface temperature with wear land for a constant heating current of 150 amperes and for a particular speed of 166 m/min. In both the cases of using relay and without using relay, feed force increases as the flank wear land progresses. The increase in feed force in case of using relay is 14 percent whereas the increase is 18 percent in the case of machining without using relay. Chip-tool interface temperature increases with the increase in wear land and the trend of behaviour is same for both the cases. Surface finish gets poorer with the increase in wear land but machining without using relay causes considerably poor surface finish.

5.4.6 Variation of Flank Wear with Time :

Fig. 17 represents variation of flank wear with time when machining was performed using relay for the heating current of 0 to 150 amperes. It is found that the length of flank wear increases linearly with time after an initial rapid wear. In this investigation, the length of flank wear of 0.25 mm. is selected as the criterion for tool life measurement.

Table 1 compares the tool life values obtained in the present investigation with those of Dey. It can be said that machining with the relay in use improves tool life slightly than when machining is done by avoiding sparking through manual control.

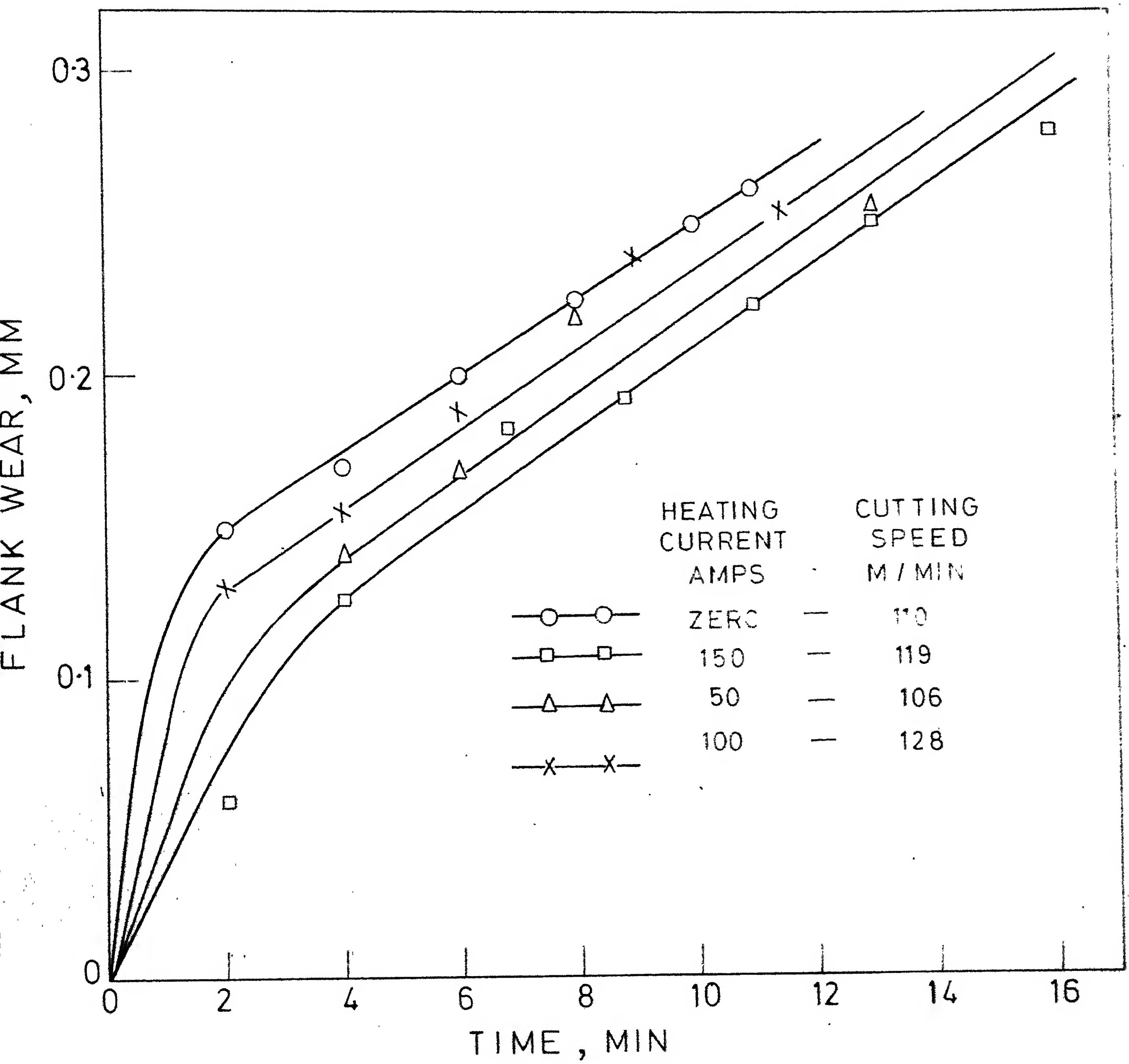


FIG.17 VARIATION OF FLANK WEAR WITH TIME FOR DIFFERENT HEATING CURRENT

TABLE - 1

TOOL LIFE COMPARISON

HEATING CURRENT (AMPS)	CUTTING SPEED (M/MIN)	TOOL LIFE (MIN.)	
		PRESENT INVESTIGATION	DEY'S INVESTIGATION
100	128	11	9
150	119	13	12

CHAPTER - 6

CONCLUSIONS

6.1 Conclusions :

The following conclusions are drawn from the experimental investigation on hot machining of En-24 steel with carbide tips using a relay circuit.

a) The feed force decreases with the increase in heating current in both the conditions of machining with relay and without relay. The decrease in feed force in the former condition is 14 percent upto 250 amperes whereas, in the latter condition, it is only 7 percent. In the case of machining without using relay, feed force is more than that obtained in the condition of using relay for all the heating currents.

b) Surface finish improves with the increase in heating current in the case of machining with relay. Machining without the use of relay deteriorates surface finish drastically for all the heating currents. Thus use of relay improves surface finish considerably.

c) The optimum range of heating current lies between 100 and 150 amperes for minimum flank wear in the case of machining with relay. But machining without the use of relay shifts the optimum current range to 50 - 100 amperes. Keeping other machining aspects same, there is a decrease of 25 to 60 % in the length of flank

wear upto 150 seconds of cut when the machining is done with the relay in use.

d) Chip-tool interface temperature increases with increasing heating current and interface temperature is not much affected whether machining is done with the relay in use or without the relay.

e) Feed force, chip-tool interface temperature and surface roughness increase with the increase in wear land for both the conditions of machining with relay and without relay. The increase in feed force for 150 seconds of cut is 14 percent and 18 percent when machining is done with the relay in use and without the relay respectively. Machining without using relay causes considerably poor surface finish than when machining is performed with the relay in use.

APPENDIX - A

1. Properties of En-24 steel [36] :

Nominal Percentage Composition:

C, 0.35-0.45; Si, 0.10-0.35; Mn, 0.45-0.70;

S, 0.50 max; P, 0.05 max; Ni, 1.30-1.80;

Cr, 0.90-1.40; Mo, 0.20-0.35.

Tensile strength, tons/sq.in.min.: 53.1

Yield stress, tons/sq.in.min: 36.25

Brinell hardness No.: 223/277

Machinability : Approximately 53 % of mild-steel.

2. Properties of Carbide Tool Material :

Percentage Composition:

WC, 0.76; Co, 0.08; TaC, 0.04; TiC, 0.12

Abrasion resistance	:	Low
Impact resistance	:	High
Crater resistance	:	High
Young's modulus	:	90×10^{-6} psi
Rockwell Hardness		
" A " Scale	:	92
Hot working temperature	:	Retains hardness upto $1000^{\circ}C$ approximately.

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